DEPARTMENT OF THE AIR FORCE
HEADQUARTERS AIR FORCE CIVIL ENGINEER SUPPORT AGENCY

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FROM: HQ AFCESA/CES
139 Barnes Drive, Suite 1
Tyndall AFB, FL 32403-5319

SUBJECT: Engineering Technical Letter (ETL) 05-8: Use of Off-the-Shelf Concrete Admixtures as Cold Weather Admixture Systems (CWAS).

1. Purpose. This ETL provides guidance to design, mix, place, and cure concrete in below-freezing weather.

Note: The use of the name or mark of any specific manufacturer, commercial product, commodity, or service in this ETL does not imply endorsement by the Air Force.

2. Application: All Air Force organizations with concrete construction, maintenance, and repair responsibility.

2.1. Authority: Air Force policy directive (AFPD) 32-10, *Air Force Installations and Facilities*, and Air Force instruction (AFI) 32-1023, *Design and Construction Standards and Execution of Facility Construction Projects*.

2.2. Coordination: Major command (MAJCOM) pavement engineers.

2.3. Effective Date: Immediately.

2.4. Ultimate Recipients:

- Air Force MAJCOM pavement engineers.
- Base civil engineers (BCE), RED HORSE, and other units responsible for design, construction, maintenance, and repair of concrete structures.
- U.S. Army Corps of Engineers (USACE) and Navy offices responsible for Air Force design and construction.

3. Referenced Publications.

3.1. Air Force:

- AFPD 32-10, *Air Force Installations and Facilities*, available at http://www.e-publishing.af.mil/
- AFI 32-1023, *Design and Construction Standards and Execution of Facility Construction Projects*, available at http://www.e-publishing.af.mil/

3.2. Army:

- Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory Technical Report (ERDC/CRREL TR) 04-2, *Extending the Season For Concrete Construction and Repair: Phase I—Establishing the Technology*, available at http://www.crrel.usace.army.mil/techpub/CRREL_Reports/reports/TR04-2.pdf

- ERDC/CRREL TR-05-9, *Placing Antifreeze Concrete at Grand Forks Air Force Base*, available at http://www.crrel.usace.army.mil/techpub/CRREL_Reports/reports/TR05-9.pdf

3.3. Industry:

- American Concrete Institute (ACI) 306-R88, *Cold Weather Concreting*, available at http://www.concrete.org/BOOKSTORE/bkstr.asp
- American Society for Testing and Materials (ASTM) C33, *Standard Specification for Concrete Aggregates*, available at http://www.astm.org
- ASTM C150, *Standard Specification for Portland Cement*, available at http://www.astm.org

4. Acronyms and Terms:

ACI	- American Concrete Institute
AEA	- air-entraining admixture
ASTM	- American Society for Testing and Materials
BCE	- base civil engineer
C	- Celsius
CWAS	- cold weather admixture system
ERDC/CRREL	- Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory
ETL	- Engineering Technical Letter
FHWA	- Federal Highway Administration
kg	- kilogram
kg/m^3	- kilograms per cubic meter
L	- liter
m^3	- cubic meter
MAJCOM	- major command
MB	- Master Builders, Inc.
mL	- milliliter
mm	- millimeter
NH	- New Hampshire
NMSA	- nominal maximum size aggregate
RED HORSE	- Rapid Engineers Deployable - Heavy Operational Repair Squadron Engineers
rpm	- revolutions per minute
TR	- Technical Report
USACE	- U.S. Army Corps of Engineers
w/c	- water/cement
WI	- Wisconsin
WRG	- W.R. Grace & Co.

5. Objective. This ETL provides information for combining ordinary concrete admixtures into cold weather admixture systems (CWAS) that depress the freezing point of water to at least –5°C and accelerate the hydration rate of Portland cement while at that low temperature.

6. Background.

6.1. Currently, there are no commercially available admixtures that, when used alone, will prevent fresh concrete from freezing at an internal temperature of –5°C. Admixtures are available that allow concrete to gain strength at air temperatures below 0°C, but these admixtures, when used at their recommended dosages, will not prevent freezing. They promote strength gain by accelerating cement hydration, which increases the rate of internally generated heat to help maintain concrete temperatures above freezing until enough strength is developed to resist damage from freezing.

6.2. This ETL presents the tools to design, mix, place, and cure concrete made with combinations of commercial off-the-shelf admixtures in below-freezing weather. Because standard practice places no limitations on the number of admixtures that may be used in concrete—just on individual dosages—several admixtures were combined to produce the desired low-temperature effect. This ETL is based on the results of laboratory tests and field studies obtained between 1 October 2000 and 1 October 2003 under the Federal Highway Administration (FHWA) State Planning and Research Pooled Fund Study TPF-5(003), *Extending the Season for Concrete Construction and Repair: Phase I—Establishing the Technology* (ERDC/CRREL TR-04-2), and on a demonstration of the resulting technology at Grand Forks Air Force Base, North Dakota (ERDC/CRREL TR-05-9, *Placing Antifreeze Concrete at Grand Forks Air Force Base*).

7. Definition of Cold Weather Admixture System (CWAS). CWAS is defined as any commercial chemical admixture or combination of commercial chemical admixtures that depresses the freezing point of mixing water and accelerates the hydration rate of Portland cement in concrete. The term *antifreeze admixture* may be used interchangeably with the term *CWAS*. Concrete containing a CWAS may be referred to as *antifreeze concrete*.

8. Function of CWAS. The primary functions of CWAS are to prevent fresh concrete from freezing at an internal temperature as low as –5°C and to promote strength gain at that temperature at least as fast as normal concrete cured at 5°C. The secondary function is to create an antifreeze concrete mixture that behaves like conventional concrete at time of placement.

9. Materials.

9.1. Aggregate. Aggregates, both fine and coarse, that are approved for normal concreting practice are acceptable for antifreeze concrete. The aggregates used to develop this ETL were locally available, clean and well graded to produce workable concrete mixtures, and were known to be durable. There are no size restrictions, but the nominal maximum size coarse aggregate (NMSA) used to develop this ETL was 19 millimeters for all tests except the Rhinelander, Wisconsin, field trial (ERDC/CRREL TR-04-2), which used a 38-millimeter NMSA coarse aggregate. Typically, coarse aggregates used in pavements are larger than those used in other concrete structures; the Rhinelander job was a pavement, while the other jobs were not. The fine aggregates in all cases were natural sands meeting the specifications of ASTM C33, *Standard Specification for Concrete Aggregates*.

9.2. Cement.

9.2.1. The testing for this ETL was limited to Portland cement. Though blended cements such as fly ash, blast furnace slag, or silica fume combined with Portland cement are common in general construction, they were not included because it was decided that the antifreeze technology should be proven on Portland cement first. Now that the antifreeze properties of admixtures for winter concrete construction are proven, this technology should be expanded to include other cements.

9.2.2. Portland cements that are specified for cold weather concreting are acceptable for antifreeze concrete. Cements that conform to ASTM C150, *Standard Specification for Portland Cement*, Type I and Type III, are usually specified for winter concreting. This ETL allows Type I and Type II cements, plus a combination Type I/II cement. Type III, high early strength cement, was not studied because it is not widely available. The Type II cement, though it generates less heat and at a slower rate than Type I, is permissible because the high doses of accelerating admixtures used to formulate the CWAS should overcome most tendencies for slow strength development. The Type II cement has performed quite well in past studies and is recommended for use with the admixtures approved in this ETL.

9.2.3. In today’s practice, obtaining high early age strength is advantageous in cold weather to decrease the length of time that thermal protection is necessary. This ETL focuses on that concept. The usual methods of achieving high early strength are to use all Type III cement, use additional Type I cement, or use chemical accelerators. One admixture formulation, WRG IV in the FHWA project report (ERDC/CRREL TR-04-2), used a retarding admixture expressly to slow down the slump loss characteristic of concretes made with high doses of accelerating admixtures. Unfortunately, the retarder did little to solve the early stiffening problem, but it delayed strength gain, which was viewed as a negative consequence. However, for bridge deck applications, where delayed strength gain may be desirable, a retarded mix such as WRG IV might prove useful. But, because the focus of the studies leading up to this ETL was on rapid strength gain, the WRG IV formulation was not included in this ETL.

9.2.4. To create antifreeze concrete with high early age strength, it is recommended to use at least 363 kilograms per cubic meter (kg/m^3) of Type I, Type II, or Type I/II cement. The lowest cement factor used in this ETL is 392 kg/m^3, while the highest is 476 kg/m^3. Also, the water/cement (w/c) ratio should be kept at or below 0.45 in accordance with current guidance for durable concrete. Lower w/c ratios, besides further increasing durability and enhancing strength gain, also lessen the amount of admixture needed for freezing point depression.

9.3. Water. Water approved for making normal concrete can be used as mixing water for making antifreeze concrete. Cold water, as explained later, should be used to batch all antifreeze concrete mixtures to slow down slump loss. The recommended initial temperature of the concrete is 10°C ± 5°C.

9.4. Chemical Admixtures. To avoid compatibility problems among admixtures and limit the possible combinations of admixtures to investigate, this ETL concentrates on the product lines of W.R. Grace & Co. (WRG) and Master Builders, Inc. (MB). (Admixtures from other sources could similarly be used, but they should be tested in laboratory and field trials to be sure they produce the desired results.) Table 1 shows six admixture combinations that were found to be useful for antifreeze concrete. (The FHWA project report [ERDC/CRREL TR-04-2] lists eight admixture combinations that provided antifreeze protection; however, the WRG IV and MB III combinations were not included in this ETL because the former mix caused concrete to gain strength too slowly and the latter tended to disentrain air from the concrete.) The six admixture combinations were developed after numerous trials to yield concrete with the desired –5°C freezing point, reasonable transit life, and good jobsite workability. Of all the commercial admixtures marketed today, these six combinations are not the only possible antifreeze combinations, but they were chosen because they performed well. They are not even the only possibilities when using the products from the two companies chosen for this study. However, Table 1 should serve as the basis for proportioning antifreeze concrete mixtures until more information becomes available. The admixtures in Table 1 were tested in laboratory concretes containing 392 kg/m^3 cement and the w/c ratios shown.

Table 1. Recommended Dosages of Six Combinations of Commercial Admixtures to Protect Fresh Concrete Against Freezing.

Product Name	Admixture Dosage		
	W.R. Grace & Co.		
	I†	II	III
Mira 70 (mL/100 kg cement)	780	585	390
ADVA Flow (mL/100 kg)	195	98	65
DCI (L/m^3 concrete)	30	–	30
DCI-S (L/m^3)	–	30	–
PolarSet (L/100 kg)	6.52	6.52	6.52
Eclipse Plus (percent of cement weight)	–	–	1
Darex II AEA (mL/100 kg)	60‡	30‡	20
w/c ratio	0.442	0.452	0.442
	Master Builders, Inc.		
	I	II	IV
Polyheed 997 (mL/100 kg)	780	780	780
Glenium 3000 NS (mL/100 kg)	195	195	–
Rheocrete CNI (L/m^3)	30	30	30
Pozzutec 20 (L/100 kg)	5.87	5.87	–
Pozzutec 20+ (L/100 kg)	–	–	5.87
Pozzolith100-XR (mL/100 kg)	–	65	–
MB-VR Standard (mL/100 kg)	40‡	20‡	20
w/c ratio	0.430	0.431	0.390

* The performances received with these admixture dosages may vary from cement to cement.

† Roman numerals correspond to six admixture combinations developed for this ETL.

‡ It may be necessary to redose with an air-entraining admixture (AEA) at the jobsite

10. Proportioning Antifreeze Concrete. Until one becomes familiar with the process for formulating CWAS, the recommended approach to proportioning antifreeze concrete mixtures is to begin with a standard concrete used in warm-weather construction and that is workable, durable, and strong. The procedure to convert a standard concrete into antifreeze concrete is to choose one of the admixture combinations from Table 1, verify that it can produce a –5°C freezing point, and conduct field trials to determine the optimum admixture dosing sequence to achieve target slump, air content, and working time.

10.1. Step 1: Select Standard Concrete. As described in paragraph 9.2.4, select a concrete mixture that contains at least 363 kg/m^3 cement, has a 0.45 or lower w/c ratio, and is workable. Five standard concretes were selected for field demonstration in the FHWA project (ERDC/CRREL TR-04-2) as shown in Table 2. Each concrete in Table 2 typically had a 100-millimeter slump immediately after mixing. This ETL will follow the conversion and subsequent demonstration of the Littleton, New Hampshire mix.

Table 2. Mixture Proportions of Five Warm-Weather Concretes Selected for Conversion to Antifreeze Concretes, and Subsequent Field Evaluation.

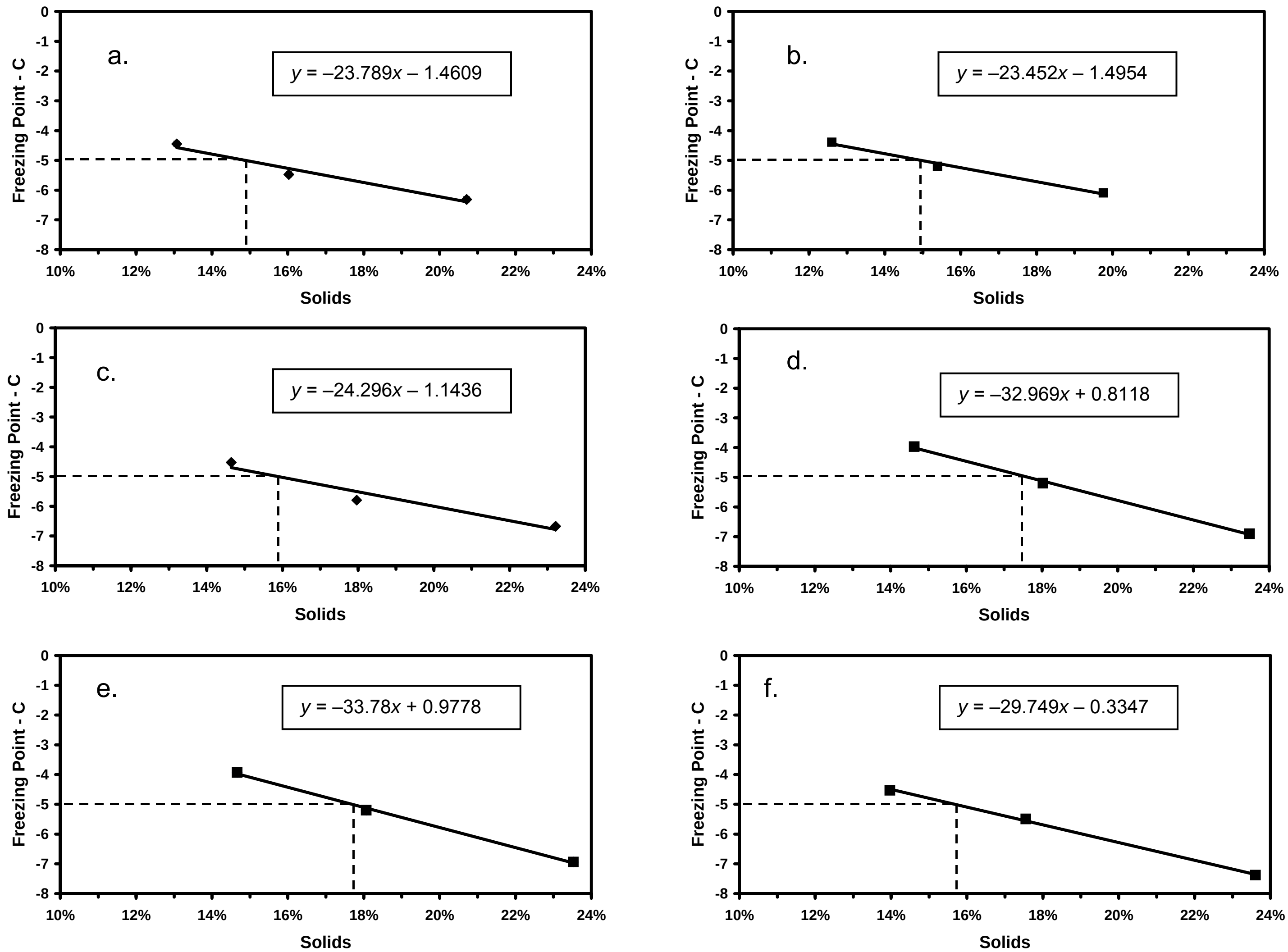
Ingredient	Littleton, NH	Rhinelander, WI	North Woodstock, NH	West Lebanon, NH	Concord, NH
Cement (kg/m^3)					
Type I	–	476	–	–	–
Type I/II	–	–	–	392	–
Type II	392	–	392	–	392
Aggregate (kg/m^3)					
Coarse—19mm	1042	950	1050	1083	1050
Coarse—38mm	–	179	–	–	–
Fine—sand	680	780	699	804	699
AEA* (mL/m^3)					
Darex II	78	–	233	97	233
Catexol AE260	–	252	–	–	–

Ingredient	Littleton, NH	Rhinelander, WI	North Woodstock, NH	West Lebanon, NH	Concord, NH
Water-reducing admixture (L/m^3)					
Mira 70	0.514	–	–	0.512	–
Catexol 2000N	–	1.868	–	–	–
WRDA-Hycol	–	–	0.766	–	0.766
w/c	0.436	0.413	0.444	0.436	0.444

* Air-entraining admixture

10.2. Step 2: Verify Freezing Point.

10.2.1. To verify that a –5°C freezing point is achievable it is necessary to calculate the percent solids from the admixtures by weight of free water in the concrete. The freezing point can then be determined from Figure 1, which shows the relationship between solids content and initial freezing point. These data can be used to predict freezing points for antifreeze concretes made with the admixture combinations in Table 2. Similar curves must be developed for other admixture combinations. Each graph represents one admixture combination from Table 1: a—WRG I; b—WRG II; c—WRG III; d—MB I; e—MB II; f—MB IV.



y = freezing point
x = solids content, decimal form

Figure 1. Relationship Between Weight Of Solids Contributed by Admixtures In Percent by Weight of Free Water and Initial Freezing Point of Freshly Mixed Concrete.

10.2.2. Equation 1 calculates the weight of solids contributed to the concrete when the addition rate of admixtures is based on cement content[1]. Table 3 provides needed information about each admixture.

Equation 1:

$$Weight\,of\;solids = Dosage \times Cement\,Factor \times Sp.gr. \times Solids\,Content$$

Table 3. Physical Values of Individual Admixtures

Admixture	Solids Content (%)	Specific Gravity
Mira 70	23.5	1.1
Adva Flow	31.2	1.057
DCI	33	1.273
DCI-S	32.5	1.275
PolarSet	41.1	1.35
Eclipse Plus	100	0.945
Darex II	12	1.005
Polyheed 997	47.5	1.270
Glenium 3000 NS	30	1.08
Rheocrete CNI	32.5	1.295
Pozzutec 20	49.5	1.38
Pozzutec 20+	40	1.35
Pozzolith 100-XR	47	1.22
MB-VR	13	1.038

10.2.3. The Littleton, concrete used the WRG II admixture combination. Mira 70 was dosed at 585 mL/100kg of cement (Table 1). Substituting this value, a specific gravity of 1.1, a solids content of 23.5% (Table 3), and a 392 kg/m^3 cement factor (Table 2) into equation 1 yields 0.593 kilogram solids (1.93 kilograms water), as shown below. This is the weight of solids that Mira 70 contributes to a cubic meter of concrete. In like manner, Adva Flow, PolarSet, and Darex II contribute 0.127 kilogram, 14.181 kilograms, and 0.035 kilogram solids,[2] respectively (0.280 kilogram, 20.321 kilograms, and 0.257 kilogram water, respectively).

$$\frac{585\,\text{mL}}{100\,\text{kg cement}} \times 392\,\text{kg cement} \times 1.1 \times 0.235 = 0.593\,\text{kg/m}^3$$

[1] The weight of water contributed by each admixture can be calculated by simply substituting [1-solids content] for the solids content.
[2] An extra 44 mL/100 kg of Darex II was added at the jobsite.

10.2.4. For admixtures whose addition rates are based on concrete volume, the weight of solids is calculated by Equation 2. According to Table 1, DCI-S was dosed at a rate of 30 L/m^3. Substituting this value, a specific gravity of 1.275 and a solids content of 32.5% into Equation 2 yields 12.431 kilograms solids (25.819 kilograms water) per cubic meter of concrete.

Equation 2:

$$Weight\,of\ solids = Dosage \times Sp.gr. \times Solids\,Content$$

$$\frac{30\ \text{L}}{\text{m}^3} \times 1.275 \times 0.325 = 12.431\ \ \text{kg/m}^3$$

10.2.5. The percent solids contributed by WRG II to the Littleton concrete is equal to the weight of solids contributed by all the admixtures divided by the theoretical free water content[3] of the concrete (170.9 kilograms = w/c ratio × cement factor [Table 2]). In this case the WRG II combination was designed to contribute 16 percent solids by weight of water (27.367 kilograms solids/170.9 kilograms water). (The amount of water the ready-mix plant would add into the mixture would be 122.3 kilograms [170.9 kilograms – 48.6 kilograms]).

10.2.6. Finally, the freezing point of this concrete is found to be –5.2°C (Fig. 1.b). In a perfect world, each admixture could be reduced to raise the freezing point to –5°C. However, because it is difficult to accurately control moisture when batching ready-mix concrete, it is best to slightly overshoot the target freezing point.

10.3. Step 3: Trial Batches.

10.3.1. Three approaches for dosing the admixtures into the concrete were devised to ensure that an acceptable concrete could be produced. Because variations in jobsite conditions and concrete-making materials affect concrete performance, it is strongly recommended that trial tests be done to determine which approach works best before placing concrete on a job. Each approach is detailed in Attachment 1 and briefly described below. Control of workability and air content are concerns to address. As discussed in paragraph 13.2, the ability to measure the freezing point of the concrete needs to be refined.

10.3.2. The first approach is to mix all ingredients at the ready-mix plant. The advantage of this approach is that once the truck leaves the plant no further effort is needed to prepare the concrete. However, because the tested antifreeze concretes tended to lose slump rapidly, future antifreeze concretes should have a high initial slump to accommodate any loss during transit and still be workable during placement. In this ETL, initial slump values of 150 to 225 millimeters

[3] Includes water from aggregate, water from admixtures, and water added into the mixture.

yielded acceptable results during placement. Slowly agitating the concrete while in transit was helpful for maintaining slump. The initial air content should also be high to account for air lost during transit, as some admixtures tend to be harsh on entrained air. It was found that initial air contents between 8 percent and 10 percent produced target value air contents during placement. Re-dosing the mix at the jobsite with plasticizer or air-entraining admixture or both may be necessary with some mixes. This first approach is best when the haul time is no more than 45 minutes and the concrete can be immediately dispensed within 20 minutes.

10.3.3. The second approach is to add half of the admixtures into the concrete at the ready-mix plant and the rest at the jobsite. The non-accelerating admixtures, if any, should be added first. This approach requires that admixtures be transported to the jobsite and pumped into the truck. Though requiring extra effort, it provides more assurance that the concrete will be workable, as slump loss is less of a factor until the final admixture is added into the concrete. Re-dosing the mix at the jobsite with an air-entraining agent may not be necessary with this approach. However, working time tends to decrease very rapidly once the last admixture is added, so the concrete must be dispensed quickly—usually within 30 minutes. This approach may allow haul times of as long as one hour.

10.3.4. The third approach is to mix all of the admixtures into the concrete at the jobsite. This approach requires the most effort, but the admixtures do not have to be dosed until the construction crew is ready for the concrete and it allows 45 minutes or longer for working time. Because the concrete must leave the ready-mix plant with a very low w/c ratio to account for the water in the admixtures, the air-entrained admixture (AEA) is best added into the mix at the jobsite.

11. Field Demonstrations.

11.1. Once trial batches prove that an acceptable antifreeze concrete can be produced, it is ready for full-scale use. The Littleton demonstration project (ERDC/CRREL TR-04-2) is used as an example.

11.2. Because the estimated haul time to the Littleton project was 30 minutes, it was felt that Approach 2, paragraph 10.3.3, could be followed. Consequently, all but the PolarSet and some of the AEA were withheld from the batch until the truck arrived at the jobsite (Table 4). Once there, a quick visual check revealed that the concrete had a slump of about 100 millimeters, which was higher than the expected 70 millimeters determined by the trial tests. This immediately suggested that the water content of the mixture was high. However, because the solids content was designed to be higher than necessary, no adjustments were made and the PolarSet and AEA were added into the truck. The resulting slump, measured with a slump cone, was 203 millimeters. Because the mix was cohesive, the concrete could have been immediately placed into its forms, but it was elected to slowly agitate it for 20 minutes at 2 to 4 revolutions per minute (rpm) until it began to lose slump. Once that happened, the concrete was placed during the next 40 minutes, dropping to the target slump of 100 millimeters. The freezing point of the concrete was unknown at this point[4].

Table 4. Dosing Schemes Used in the Five Field Studies.

Ingredient	Littleton, NH	Rhinelander, WI	North Woodstock, NH	West Lebanon, NH	Concord, NH
Freezing point and accelerating admixture (L/m³)					
DCIS	29.84	[18.5]	–	–	–
DCI	–	[11.3]	–	–	–
PolarSet	[25.56]*	[30.9]	–	–	–
Rheocrete CNI	–	–	[29.8]	29.8	[29.8]
Pozzutec 20+	–	–	[23.0]	23.0†	[23.0]
AEA‡ (mL/m³)					
Darex II	116 [170]	–	–	–	–
Catexol AE260	–	407 [156]	–	–	–
MB-VR	–	–	[38.9]	78	[38.9]
Water-reducing admixture (L/m³)					
Mira 70	2.293	[3.74]	–	–	–
Adva Flow	0.389	[0.934]	–	–	–
Polyheed 997	–	–	[2.289]	2.289	[2.304]

* Brackets denote jobsite additions; all other numbers indicate ingredients added into the concrete at the ready-mix plant.

† This admixture was pumped into the truck but not mixed into the concrete until the truck reached the jobsite.

[4] This pooled-fund project did not include as one of its goals the measurement of freezing point. However, there is no way to know that the concrete fully met expectations unless such a measurement is made. An expedient measurement method is described in paragraph 13.2 and in more detail in ERDC/CRREL TR-04-2. Our field measurements showed that the Littleton concrete's freezing point was –5.2°C. It was fully acceptable. Attachment 2 shows that freezing point measurements can used to backcalculate actual w/c ratios.

‡ Air-entraining admixture

11.3. The other field tests, except for the West Lebanon test (ERDC/CRREL TR-04-2), dosed most admixtures into the concrete at the jobsite. With today's admixture pumps this was not viewed as a difficult task. This scheme provided full assurance that the load would not stiffen during transit and that the concrete could be easily adjusted on site to give the desired workability. The West Lebanon test tried an interesting variation: all admixtures were dosed at the ready-mix plant, except that one admixture was not mixed into the concrete—it was merely pumped into the truck and then mixed once the truck arrived at the jobsite. This scheme avoided the need for admixture pumps at the jobsite altogether and provided highly workable concrete.

12. Production and Placement. Antifreeze concrete mixtures are sensitive to water content when it comes to freeze protection. They tend to lose slump very rapidly, are sticky to finish, and require close control of when admixtures are added into the mixing process. However, they show no tendency to bleed when properly batched, so the finishing operation can be started almost immediately after the concrete is consolidated and leveled. Even at very low slumps, the concretes have responded well to vibration.

12.1. Ready-Mix Plant.

12.1.1. The ready-mix plant should be within a 30-minute drive of the jobsite to allow time for positioning the truck and making any final adjustments to the concrete (longer drives are permissible if all admixtures are dispensed at the jobsite). Because of the need to create a concrete of a certain freezing point, accurate moisture control is critical. Ready-mix plants should have moisture meters to continuously monitor changes in the sand as it is batched. The moisture content of the coarse aggregate should be measured at the start of each day and whenever the slumps start to deviate. For example, in the FHWA study (ERDC/CRREL TR-04-2), moisture contents were obtained from grab samples taken from the sand and coarse aggregate piles a few hours before batching. However, it was found that accurately measuring aggregate moisture proved difficult. In the first three field trials, the actual water content of the concretes was higher than designed. Snow in the aggregate piles was considered responsible for errors in measurement.

12.1.2. In response to these difficulties, the aggregate moisture contents in the final two field trials were assumed to be somewhat greater than the grab sample measurements indicated. This led to both concretes containing lower w/c. In these instances, extra water could have been added into the mix.

12.1.3. Unless better moisture control is possible, it is recommended that the ready-mix plant withhold up to 25 L of batch water from every cubic meter of concrete. Once all admixtures are mixed into the concrete, then the withheld water should be carefully mixed into the concrete until it attains the desired slump as developed in the trial batches.

12.2. Truck Driver.

12.2.1. Before batching, truck drums should be reversed for numerous rotations to ensure no wash water is in them. It is also recommended not to wash down the fins after loading to avoid getting extra water into the drum. If this is not possible, then the ready-mix plant should withhold extra water to account for the wash water. The truck driver should demonstrate his washing technique in several trials so the amount of wash water can be reasonably estimated. Until better data becomes available, it can be estimated that 10 to 15 L of water are used to wash down fins.

12.2.2. The same driver should be used during both the trial batches and the actual jobsite placement. If the truck has a resistance meter, the driver should observe its readings during several parts of the trials to know when the concrete has good slump and, more importantly, when it has begun to stiffen. Adding water at this point will loosen the mixture, but waiting too long may create problems.

12.2.3. During transit, the mix should be slowly agitated at 2 to 4 rpm if trial batches indicate rapid stiffening of the mix. Once at the jobsite and with the truck positioned it is recommended that the concrete be mixed 15 revolutions if no admixtures are added into the truck and 30 revolutions if admixtures are added.

12.2.4. Though not experienced in the FHWA study (ERDC/CRREL TR-04-2), during field placements the last part of the load may become difficult to discharge; if this happens, batch size should be reduced. Typically, it is recommended that the maximum batch size be limited to half—but no more than two-thirds—of the mixing capacity of the truck. Half-capacity is recommended for the first few loads until experience is gained with the particular concrete being used. Batch size may be increased if conditions warrant.

12.2.5. The concrete is made with cold water, but it is important to have hot water in the truck's water tank. The hot water will prevent the truck's hoses and nozzles from freezing up during cleanup operations.

12.3. Job Supervisor.

12.3.1. Successful use of antifreeze concrete requires close coordination between the ready-mix plant, the concrete truck driver, and the concrete construction crew. A pre-construction meeting should be held with these key individuals to inform them how the concrete should behave during batching, transport, and placement—and particularly how quickly the concrete can stiffen.

12.3.2. Because antifreeze concrete stiffens very rapidly, concrete that is not used should be temporarily disposed of at a predetermined jobsite location. If this is not possible, instruct the truck driver to water down the waste concrete until it has a soupy consistency; otherwise the paste may harden onto the truck's fins, requiring extra effort to clean out the drum. Alternatively, one could use a hydration-controlling admixture to prevent the concrete from hardening on the trip back to the ready-mix plant.

12.3.3. Trial mixing is recommended because conditions and materials vary with location. Several 2- to 4-cubic-meter trial batches should be made to confirm mixture proportions and to give participants a feel for how the concrete will behave during each stage of the process. The trial batches should be used to define the proper amounts, sequencing and timing of the admixtures based on their response to the particular cement being used. Obtain periodic slump measurements, air content, and concrete temperature readings to verify that the concrete mixture will behave as desired throughout the time of placement. The trial batches provide the opportunity to experiment with different admixture dosing schemes for training the batch plant, truck driver, and job supervisor in working with antifreeze concrete. As with all new construction methods, there will be a learning curve.

12.3.4. Though the antifreeze concrete produced as recommended in this ETL is capable of resisting freezing to –5°C, it is not possible at this point to forecast to what outdoor temperature this translates. The thermal profile of curing concrete is a function of the mixture proportions, its geometry, the amount of wind and solar radiation, and the type of formwork. Until the hydration process is better characterized for low-temperature application, the best guidance that can be provided is that antifreeze concrete can be placed when the air temperature is at least –20°C and rising. The concrete was placed in sections as thin as 140 millimeters on gravel when the air temperature started out at approximately –20°C, rose to about –10°C over the next six hours, and then dropped to below –20°C that night. The concrete section was covered with a 25-millimeter-thick insulation blanket.

12.3.5. When removing formwork, you should consider ensuring that the concrete is not exposed to a large thermal gradient. Follow guidance provided in ACI 306-R88, *Cold Weather Concreting*.

12.4. Placing and Finishing.

12.4.1. The substrate against which fresh concrete is to be placed must be free of ice and snow. It is permissible for its temperature to be below freezing, but all sources of excess water must be removed.

12.4.2. The behavior of antifreeze concrete in its plastic state is very similar to that of high-cement-content, low-w/c-ratio concrete. Like conventional concrete, it is sticky to finish but tends to lose its stickiness as slump decreases. The objective is to produce a uniformly dense cross-section that will be suitable for the service conditions. The serviceability of a concrete surface is often affected by the finishing procedures. It is important for durability and wear resistance not to overwork the surface.

12.4.3. The concrete should be continuously placed within 20 to 30 minutes or according to the working time determined during the trial batching tests. As the concrete is placed, immediately strike off excess concrete to bring the surface to proper elevation; this can be done either mechanically or by hand with a straightedge. Following screeding, bull float the surface to embed aggregate and smooth the surface. Be careful not to seal the surface. Some tearing when using a magnesium float is not undesirable. Wait until the concrete can be walked upon without leaving footprints more than 0.25-inch deep before floating. Floating too early is likely to cause dusting and crazing because floating tends to bring cement paste to the surface. A float finish followed by scratching the surface with a broom is often recommended for flatwork exposed to outdoor conditions. Stopping at this point provides a durable, uniform, non-skid surface and avoids problems caused by over-troweling.

12.4.4. If troweling is desired, a single troweling pass, rather than several, is preferred. The purpose of troweling is to produce a hard, smooth surface. Minimal troweling should leave a somewhat rough surface without creating a weakness at that level. Overworking the surface can lead to a weak surface layer caused by working in too much water and a surface susceptible to frost action because of a diminished air content caused by too much mechanical action.

12.4.5. Once finishing is completed, exposed surfaces must be protected against drying out or otherwise strength and wear resistance will suffer. The surface should be covered with a sheet of plastic or a spray-on curing compound (or both) as soon as the surface is tack-free. This happens very quickly. Wrinkle-free application of the plastic sheet helps to ensure a uniformly colored surface. Cover protruding metal with insulation since metal can act as a heat sink to freeze surrounding concrete. Be sure to insulate the ends of metal form ties.

12.4.6. If sawed joints are necessary, sawing should be done when test cuts have sharp, clean edges.

13. Quality Verification.

13.1. Strength Gain Estimates.

13.1.1. A critical question to be answered for any concrete structure is “When will it be ready for use?” There are a number of tests, both destructive and non-destructive, that can be used to determine this, but the maturity method is favored. A detailed discussion of how to develop maturity curves is provided in the FHWA project report (ERDC/CRREL TR-04-2). Common practice is to develop a maturity curve from test concrete having the same mixture proportions as the intended job concrete before starting the construction project. In practice this usually does not happen because it is difficult to plan ahead for most projects, particularly if they are small. For many projects it is important to put the structure into service as soon as possible. Thus, it is recommended that a maturity curve be developed from the job concrete as it is being placed.

13.1.2. Before placement, thermocouples should be placed at several locations where it is important to know what the strength is at any given time. Then, during placement, numerous cylinders should be cast from the fresh concrete. Typically, about one-third of the load should be placed before cylinders are cast. Install thermocouples into several cylinders. Then, allow the cylinders to cure at any convenient temperature, provided their internal temperature does not drop below –5°C, and test them, three at a time, for compressive strength. Store the cylinders indoors. The time-temperature factor recorded from the cylinders is then plotted against cylinder strength. This plot is then used to estimate in-situ strength based on the time-temperature factor recorded from the structure. Temperature data collection continues until it is determined that the structure is safe to put into service (see the FHWA project report [ERDC/CRREL TR-04-2] for more detail).

13.2. Freezing Point Measurement.

13.2.1. It is critical to know the temperature at which water in fresh concrete freezes. This temperature is affected by the type and concentration of solids dissolved in the water. This is an important parameter to know when concrete arrives at a construction site; admixtures are dosed knowing the moisture content of aggregate. However, the actual w/c ratio in ready-mix concrete can vary by several percent due to changes in aggregate moisture, measurement inaccuracies, and the tendency of contractors to add water at the site. Thus, the final freezing point of the concrete could be considerably different from desired. Unfortunately, there are no commercial devices to determine the freezing points of concrete in the field.

13.2.2. Until a better method is developed, CRREL has developed a rudimentary way to measure the freezing point of fresh concrete in the field. Because this measurement takes about 30 minutes to complete, it is most useful when used in conjunction with the trial batch operation. It is envisioned that a relationship between freezing point and slump would be the most useful product created for the concrete mixture selected for the job.

13.2.3. The freezing point method is described in the FWHA project report (ERDC/CRREL TR-04-2). However, in brief, it consists of making several 50.8- by 101.6-millimeter cylindrical samples, installing thermocouples, and placing them in a chest containing dry ice. Experience shows that these cylinders might drop below their freezing point within 20 minutes of being placed in the chest. Having the data plotted real-time onto a laptop computer facilitates rapid determination of the freezing point. Freezing points should be determined at various slumps (w/c ratios). The freezing point is identified as the location on the temperature vs. time plot (Figure 2) from the cylinders being cooled where the initial slope of the cooling curve (the mostly linear portion above 0°C) suddenly changes. The resulting relationship between freezing point and slump can then be used to estimate the as-dispensed freezing point of the concrete at the jobsite, provided the admixtures were used in the same doses as found in the trial batches.

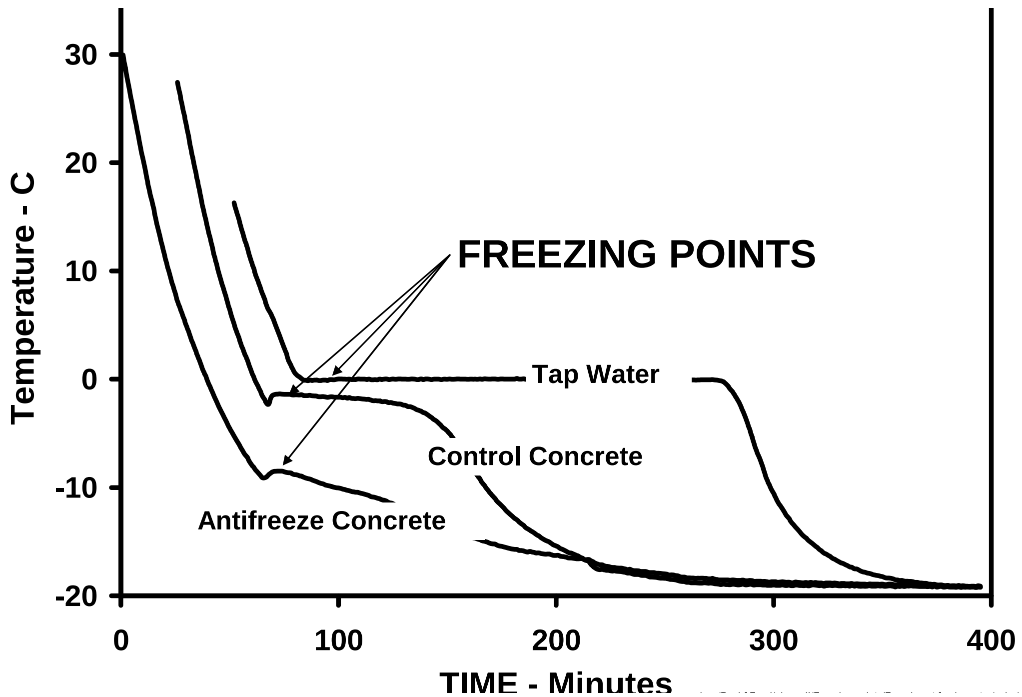


Figure 2. Cooling Curves for Water, Control Concrete, and Antifreeze Concrete.

14. Contact. Recommendations for improvements to this ETL are encouraged and should be furnished to HQ AFCESA/CESC, 139 Barnes Drive, Suite 1, Tyndall AFB, FL 32408-5319, Pavements Engineer, DSN 523-6334, commercial (850) 283-6334, internet AFCESAReachBackCenter@tyndall.af.mil.

LESLIE C. MARTIN, Colonel, USAF
Director of Engineering Support

4 Atch
1. Trial Batching
2. Determining the W/C Ratio From Freezing Point Measurements
3. Conversion Factors
4. Distribution List

TRIAL BATCHING

A1.1. The trial batches will determine the best timing for adding admixtures into the concrete. To reasonably duplicate the performance of concretes batched for jobsite application, use a minimum batch size of 2 to 4 cubic meters. Use cold water for all batching operations to create an initial concrete temperature of 10° ± 5°C. Higher temperatures tend to cause antifreeze mixtures to stiffen too rapidly and lower temperatures are difficult to achieve. The goal is to produce a concrete with acceptable slump and air content at the jobsite. Jobs with short haul times and cement content less than 400 kg/m^3 can have all admixtures added into the concrete at the ready-mix plant, whereas longer haul times or higher cement content might require that all the admixtures be added at the jobsite. Moisture control is critical to obtain a desired freezing point—determine moisture content of sand and coarse aggregate before the start of each day and as needed during the day. Reverse the drum on the truck to empty wash water from previous cleaning operations before making a trial batch.

A1.2. The three approaches developed for dosing admixtures into concrete that performed well for this ETL are presented in this attachment. The times shown simulate the time spent at the ready-mix plant, in transit, and on the jobsite, and are based on performance requirements established at the beginning of the study: 45-minute transit time and 20- to 30-minute jobsite working time. All mixing and testing of trial batches can take place at the ready-mix plant.

Approach 1. Dose all admixtures at the ready-mix plant.

Location	Operation	Time (hr:min)	
		Start – End	Total
Ready-mix plant	Add cold mixing water into drum	0:00	15 min
	Add sand, coarse aggregate and cement into drum, with AEA* on sand	0:00‡	
	Mix for 2 minutes	0:00 – 0:02	
	With mixer slowly agitating (2–4 rpm), add one of the following admixtures into the drum: DCI, DCI-S, or Rheocrete CNI†	0:02 – 0:05	
	Mix for 1 minute	0:05 – 0:06	
	Back load up to top of drum and add either Mira 70 or Polyheed 997†	0:06 – 0:08	
	Mix for 1 minute	0:08 – 0:09	
	Back load up to top of drum and add either Adva Flow or Glenium 3000 NS†	0:09 – 0:11	
	Mix 1 minute	0:11 – 0:12	
	With mixer slowly agitating (2–4 rpm), add one of the following admixtures into the drum: PolarSet, Pozzutec 20, or Pozzutec 20+†	0:12 – 0:15	
Transit	Mix for 3 minutes, then agitate at 2–4 rpm thereafter	0:15 – 0:18	45 min
	Obtain slump and air content	0:20 – 0:30	
	Obtain slump and air content	0:35 – 0:45	
	Obtain slump and air content	0:50 – 1:00	
Jobsite	Re-dose with plasticizer and AEA if needed (back up load)	1:00 – 1:20	30 min
	Obtain slump, air content, freezing point and cylinders	1:40 – 1:50	
	Immediately add water into drum and discard remaining concrete		

* Air-entraining admixture.
† Depends on the selected admixture combination.
‡ Timing starts when water hits cement.

Comments: Because all admixtures are mixed into the concrete at the ready-mix plant, the concrete may lose slump and air rapidly while in transit to the jobsite. Travel times in excess of 20 minutes may cause unacceptable slump loss with some cement, though in this study slumps could be recovered with extra plasticizer dosed into the truck after traveling up to 45 minutes. Working times of 20 to 30 minutes at the jobsite can be expected with this approach.

Approach 2. Dose some admixtures at the ready-mix plant and the rest at the jobsite.

Location	Operation	Time (hr:min) Start – End	Total
Ready-mix plant	Add cold mixing water into drum	0:00	11 min
	Add sand, coarse aggregate and cement into drum, with AEA on sand	0:00†	
	Mix for 2 minutes	0:00 – 0:02	
	With mixer slowly agitating (2–4 rpm), add one of the following admixtures into the drum: DCI, DCI-S, or Rheocrete CNI*	0:02 – 0:05	
	Mix for 1 minute	0:05 – 0:06	
	Back load up to top of drum and add either Mira 70 or Polyheed 997*	0:06 – 0:08	
	Mix for 1 minute	0:08 – 0:09	
	Back load up to top of drum and add either Adva Flow or Glenium 3000 NS*	0:09 – 0:11	
Transit	Mix for 3 minutes, then agitate at 2–4 rpm thereafter	0:11 – 0:14	45 min
	Obtain slump and air content	0:16 – 0:26	
	Obtain slump and air content	0:31 – 0:41	
	Obtain slump and air content	0:46 – 0:56	
Jobsite	With mixer slowly agitating (2–4 rpm), add one of the following admixtures into the drum: PolarSet, Pozzutec 20, or Pozzutec 20+*	1:00 – 1:03	30+ min
	Mix for 3 minutes	1:03 – 1:06	
	Obtain slump and air content	1:07 – 1:17	
	Re-dose with plasticizer and AEA if needed (back up load)	1:18 – 1:21	
	Mix for 2 minutes	1:21 – 1:23	
	Obtain slump, air content, freezing point and cylinders	1:25 – 1:35	
	Immediately add water into drum and discard remaining concrete		

* Depends on the selected admixture combination.
† Timing starts when water hits cement.

Comments: Because some admixtures are withheld from the concrete at the ready-mix plant, the concrete may not lose air as rapidly during transit as in Approach 1. However, the mix may need higher doses of plasticizer to keep it mobile during transit. Transit times of 45 minutes or more should be possible with this approach, particularly if no accelerating admixtures are in the mix. Working times might still be limited to 30 minutes at the jobsite, as slump loss is very rapid once the final admixtures are mixed into the concrete.

Approach 3. Dose all admixtures at the jobsite.

Location	**Operation**	**Time (hr:min)**	
		Start – End	**Total**
Ready-mix plant	Add cold mixing water into drum	0:00	2 min
	Add sand, coarse aggregate and cement into drum	0:00†	
	Mix for 2 minutes	0:00 – 0:02	
Transit	Agitate at 2–4 rpm	0:02 – 0:47	45 min
Jobsite	With mixer slowly agitating (2–4 rpm), add one of the following admixtures into the drum: DCI, DCI-S, or Rheocrete CNI*	0:50 – 0:53	40+ min
	Mix 1 minute	0:53 – 0:54	
	Back load up to top of drum and add either Mira 70 or Polyheed 997*	0:54 – 0:56	
	Mix 1 minute	0:56 – 0:57	
	Back load up to top of drum and add AEA that has been sprinkled into a bucket containing approximately 5 kg sand	0:57 – 0:59	
	Mix 2 minutes	0:59 – 1:01	
	With mixer slowly agitating (2–4 rpm), add one of the following admixtures into the drum: PolarSet, Pozzutec 20, or Pozzutec 20+*	1:01 – 1:04	
	Mix 3 minutes	1:04 – 1:07	
	Obtain slump and air content	1:08 – 1:18	
	Back load up to top of drum and add either Adva Flow or Glenium 3000 NS*, if needed; mix 1 minute.	1:18 – 1:21	
	Obtain slump, air content, freezing point and cylinders	1:23 – 1:30+	
	Add water into drum and discard remaining concrete		

* Depends on the selected admixture combination.
† Timing starts when water hits cement.

Comments: Because all admixtures are added at the jobsite, there is little concern about stiffening problems during delivery. The admixtures do not need to be added into the mix until the construction crew is ready. However, because the concrete is initially prepared with a very low w/c ratio, the AEA should be added at the jobsite. Transit times can easily exceed 45 minutes. There may be no need for a super-plasticizer (Adva Flow or Glenium). Working times at the jobsite can last 45 minutes or longer.

DETERMINING THE W/C RATIO FROM FREEZING POINT MEASUREMENTS

A2.1. Because the amount of admixtures and cement in most ready-mixed concretes are more accurately known (compared to water contents), a freezing point measurement can be used to estimate the actual w/c ratio of the concrete. For example, if the MB II admixture combination were used in a concrete that was found to have a –4.5°C freezing point, it is immediately known from Figure 1.e. that the water in that concrete contains 16.2 percent solids. This value, along with the amount of cement and the dosage of admixtures used to make the concrete, are all that is needed to determine the w/c. The dosage values are converted to weights of solids by following the procedure outlined in paragraph 10.2. Assuming that the admixtures contributed 35.38 kg/m^3 solids, there would be exactly 218.39 kg/m^3 water (35.38/16.2 percent) in the freshly mixed concrete. If the batch ticket indicated that 496 kg/m^3 cement were used in the concrete, a 0.44 w/c ratio is calculated. At this point the concrete could be rejected, if its freezing point was not met, or more admixture could be added into the concrete, or the structure could be thermally protected to prevent freezing.

CONVERSION FACTORS

TO CONVERT	TO	DIVIDE BY
LENGTH		
millimeters (mm)	inches (in)	25.4
centimeters (cm)	inches (in)	2.54
meters (m)	inches (in)	0.0254
meters (m)	feet (ft)	0.3048
meters (m)	yards (yd)	0.9144
kilometers (km)	miles (mi)	1.60948
AREA		
square millimeters (mm^2)	square inches (in^2)	645.16
square centimeters (cm^2)	square inches (in^2)	6.4516
square meters (m^2)	square inches (in^2)	0.00064516
square meters (m^2)	square feet (ft^2)	0.09290
square meters (m^2)	square yards (yd^2)	0.83613
square kilometers (km^2)	square miles (mi^2)	2.59043
square kilometers (km^2)	acres	0.00404
VOLUME		
cubic millimeters (mm^3)	cubic inches (in^3)	16,387
cubic centimeters (cm^3)	cubic inches (in^3)	16,487,000
cubic meters (m^3)	cubic feet (ft^3)	0.028317
cubic meters (m^3)	cubic yards (yd^3)	0.764559
MASS		
kilograms (kg)	pounds (lb)	0.45359
FORCE		
Newtons (N)	pounds (lbf)	4.44822
STRESS		
kiloPascals (kPa)	pounds per square	6.89476

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